

AMENDMENTS TO THE CLAIMS

The listing of claims will replace all prior versions and listings of claims in the application.

Claim 1. (currently amended)

A method for making an ultra-fine, submicron grain titanium or titanium-alloy article comprising the steps of:

providing a coarse grain titanium or titanium-alloy material having a first grain size;

cryogenically milling the coarse grain titanium or titanium-alloy material into an ultra-fine, submicron grain material having a second grain size less than the first grain size;

degassing the ultra-fine, submicron grain titanium or titanium-alloy material;
densifying the ultra-fine, submicron grain material to form a densified ultra-fine grain material; and

forming the article from said densified ultra-fine, submicron grain titanium or titanium-alloy material,

wherein said cryogenically milling comprises cryogenically milling said coarse grain titanium or titanium-alloy material in a slurry with a liquid selected from liquid nitrogen, liquid argon, liquid helium, liquid nitrogen mixed with liquid argon and liquid nitrogen mixed with liquid helium, and wherein said coarse titanium or titanium alloy material is a member selected from the group consisting of Ti-6Al-4V, commercially pure titanium and Ti-5Al-2.5Sn.

Claim 2. (original)

The method of claim 1, wherein forming comprises without subsequent thermal processing.

Claim 3. (original)

The method of claim 1, further comprising thermal processing after forming.

Claim 4. (original)

The method of claim 1, wherein the ultra-fine, submicron second grain size material is in the nanocrystalline range.

Claim 5. (original)

The method of claim 1, wherein densifying the ultra-fine, submicron grain material to form a densified ultra-fine, submicron grain material comprises hot isostatic pressing the ultra-fine, submicron grain material to form a densified ultra-fine, submicron grain material.

Claim 6. (original)

The method of claim 1, wherein densifying the ultra-fine, submicron grain material to form a densified ultra-fine, submicron grain material comprises Ceracon-type forge consolidating the ultra-fine, submicron grain material to form a densified ultra-fine, submicron grain material.

Claim 7. (original)

The method of claim 1, wherein densifying comprises densifying the material in an at least partially nitrogen atmosphere.

Claim 8. (original)

The method of claim 1, wherein densifying comprises densifying the material in an at least partially argon atmosphere.

Claim 9. (original)

The method of claim 1, wherein forming comprises extruding.

Claim 10. (canceled)

Claim 11. (previously presented)

A method for making an ultra-fine, submicron grain titanium or titanium-alloy article comprising the steps of:

providing a coarse grain titanium or titanium-alloy material having a first grain size;

cryogenically milling the coarse grain titanium or titanium-alloy material into an ultra-fine, submicron grain material having a second grain size less than the first grain size;

degassing the ultra-fine, submicron grain titanium or titanium-alloy material;

densifying the ultra-fine, submicron grain material to form a densified ultra-fine grain material; and

forming the article from said densified ultra-fine, submicron grain titanium or titanium-alloy material,

wherein said coarse grain titanium or titanium-alloy material is composed of Ti-6Al-4V.

Claim 12. (previously presented)

A method for making an ultra-fine, submicron grain titanium or titanium-alloy article comprising the steps of:

providing a coarse grain titanium or titanium-alloy material having a first grain size;

cryogenically milling the coarse grain titanium or titanium-alloy material into an ultra-fine, submicron grain material having a second grain size less than the first grain size;

degassing the ultra-fine, submicron grain titanium or titanium-alloy material;

densifying the ultra-fine, submicron grain material to form a densified ultra-fine grain material; and

forming the article from said densified ultra-fine, submicron grain titanium or titanium-alloy material,

wherein said coarse grain titanium or titanium-alloy material is composed of commercially pure titanium.

Claim 13. (previously presented)

A method for making an ultra-fine, submicron grain titanium or titanium-alloy article comprising the steps of:

providing a coarse grain titanium or titanium-alloy material having a first grain size;

cryogenically milling the coarse grain titanium or titanium-alloy material into an ultra-fine, submicron grain material having a second grain size less than the first grain size;

degassing the ultra-fine, submicron grain titanium or titanium-alloy material;

densifying the ultra-fine, submicron grain material to form a densified ultra-fine grain material; and

forming the article from said densified ultra-fine, submicron grain titanium or titanium-alloy material,

wherein said coarse grain titanium or titanium-alloy material is composed of Ti-5Al-2.5Sn.

Claim 14. (canceled)

Claim 15. (original)

The method of claim 1 wherein the cryogenically milling comprises cryogenically milling until the grain material is sized to between about 100-500 nanometers.

Claim 16. (original)

The method of claim 1 wherein the cryogenically milling comprises cryogenically milling until the grain material is sized to between about 100-300 nanometers.

Claim 17. (original)

The method of claim 1 wherein cryogenically milling is performed in an at least partially nitrogen atmosphere or at least partially argon atmosphere.

Claim 18. (previously presented)

The method of claim 1, wherein the step of milling comprises:
introducing said titanium or titanium-alloy material to a stirring chamber of a cryogenic milling device;
contacting said titanium or titanium-alloy material with a milling medium for a pre-determined amount of time sufficient to impart mechanical deformation into said coarse-grained titanium or titanium-alloy material to form an ultra-fine, submicron grain structure on said titanium or titanium-alloy material; and
removing said ultra-fine, submicron grain titanium or titanium-alloy material from said stirring chamber.

Claim 19. (original)

The method of claim 18, wherein the ultra-fine, submicron grain structure has a grain size between approximately 100 and 400 nanometers.

Claim 20. (original)

The method of claim 18 wherein the ultra-fine, submicron grain structure has a grain size between approximately 100 and 300 nanometers.

Claim 21. (original)

The method of claim 18, wherein the step of providing a coarse-grain titanium or titanium-alloy material having a first grain size comprises the step of providing a coarse-grain titanium or titanium-alloy material having a grain size of approximately 0.05 millimeters.

Claim 22. (previously presented)

The method of claim 18, wherein the step of forming the article from said ultra-fine, submicron grain titanium or titanium-alloy material comprises the step of cold-working the article from said ultra-fine, submicron grain titanium or titanium-alloy material.

Claim 23. (original)

The method of claim 18, further comprising cooling said titanium or titanium-alloy material to about a liquid hydrogen temperature.

Claim 24. (original)

A method as recited in claim 1 wherein milling comprises milling with a stearic acid additive.

Claim 25. (currently amended)

A method as recited in claim 18, wherein the step of forming the article ~~further comprising comprises~~ the further steps of: introducing the ultra-fine, submicron grain titanium or titanium-alloy material within a cavity of a mechanical forming die, said cavity having the general shape of a fastener or other fastening article or device;
cutting said ultra-fine, submicron grain titanium or titanium-alloy material;
removing said cut ultra-fine, submicron grain titanium or titanium-alloy material from said cold-forming die.

Claim 26. (original)

The method of claim 25 further comprising artificially-aging said cut ultra-fine, submicron grain titanium or titanium-alloy material.

Claim 27. (original)

The method of claim 25, wherein the step of introducing an ultra-fine, submicron grain titanium or titanium-alloy material within a cavity of a cold-forming die comprises the step of introducing an ultra-fine, submicron grain titanium or titanium-alloy material within a cavity of a cold-forming die using a ram.

Claim 28. (original)

The method of claim 25, wherein the step of cutting said ultra-fine, submicron grain titanium or titanium-alloy material comprises the step of cutting said ultra-fine, submicron grain titanium or titanium-alloy material using a shear device.

Claim 29. (original)

The method of claim 25 wherein the ultra-fine, submicron grain structure has a grain size between approximately 100 and 400 nanometers.

Claim 30. (original)

The method of claim 25 wherein the ultra-fine, submicron grain structure has a grain size between approximately 100 and 300 nanometers.

Claim 31. (currently amended)

A method for making an ultra-fine, submicron grain titanium or titanium-alloy article comprising the steps of:

providing a coarse grain titanium or titanium-alloy material having a first grain size;

cryogenically milling the coarse grain titanium or titanium-alloy material into an ultra-fine grain material less than the first grain size in a supercooled mixing chamber;

degassing the ultra-fine, submicron grain titanium or titanium-alloy material;

consolidating the ultra-fine, submicron grain material to form a densified ultra-fine grain material; and

forming the article from said densified ultra-fine, submicron grain titanium or titanium-alloy material,

wherein said cryogenically milling comprises cryogenically milling said coarse grain titanium or titanium-alloy material in a slurry with a liquid selected from liquid nitrogen, liquid argon, liquid helium, liquid nitrogen mixed with liquid argon and liquid nitrogen mixed with liquid helium, and wherein said coarse titanium or titanium alloy material is a member selected from the group consisting of Ti-6Al-4V, commercially pure titanium and Ti-5Al-2.5Sn.

Claim 32. (original)

A method as recited in claim 31 wherein the first grain size is about 0.05 millimeters.

Claim 33. (original)

A method as recited in claim 31 wherein the ultra-fine second grain size is between 100 and 500 nanometers.

Claim 34. (original)

A method as recited in claim 31 wherein the ultra-fine grain size is between 100 and 300 nanometers.

Claims 35. (previously presented)

A method as recited in claim 11 wherein cryogenically milling comprises cryogenically milling said coarse grain titanium or titanium-alloy material in a slurry with a liquid selected from liquid nitrogen, liquid argon, liquid helium, liquid nitrogen mixed with liquid argon and liquid nitrogen mixed with liquid helium.

Claim 36. (previously presented)

A method as recited in claim 12 wherein cryogenically milling comprises cryogenically milling said coarse grain titanium or titanium-alloy material in a slurry with a liquid selected from liquid nitrogen, liquid argon, liquid helium, liquid nitrogen mixed with liquid argon and liquid nitrogen mixed with liquid helium.

Claim 37. (previously presented)

A method as recited in claim 13 wherein cryogenically milling comprises cryogenically milling said coarse grain titanium or titanium-alloy material in a slurry with a liquid selected from liquid nitrogen, liquid argon, liquid helium, liquid nitrogen mixed with liquid argon and liquid nitrogen mixed with liquid helium.

Claim 38. (original)

A method as recited in claim 31 wherein consolidating comprises consolidating using an HIP process.

Claim 39. (original)

A method as recited in claim 31 wherein consolidating comprises consolidating using a Ceracon-type forge.

Claim 40. (original)

A method as recited in claim 31 wherein milling comprises milling with a stearic acid additive.

Claim 41. (previously presented)

A method as recited in claim 18 wherein the removing comprises removing said ultra-fine, submicron grain titanium or titanium-alloy material from said stirring chamber through an outlet.

Claim 42. (previously presented)

An ultra-fine, submicron grain titanium or titanium-alloy article produced in accordance with claim 1.

Claim 43. (previously presented)

An ultra-fine, submicron grain titanium or titanium-alloy article produced in accordance with claim 31.

Claim 44. (new)

A method for making an ultra-fine, submicron grain titanium or titanium-alloy article comprising the steps of:

providing a coarse grain titanium or titanium-alloy material having a first grain size;

cryogenically milling the coarse grain titanium or titanium-alloy material into an ultra-fine, submicron grain material having a second grain size less than the first grain size;

degassing the ultra-fine, submicron grain titanium or titanium-alloy material;

densifying the ultra-fine, submicron grain material to form a densified ultra-fine grain material; and

forming the article from said densified ultra-fine, submicron grain titanium or titanium-alloy material,

wherein said cryogenically milling comprises cryogenically milling said coarse grain titanium or titanium-alloy material in a slurry with a liquid selected from liquid nitrogen, liquid argon, liquid helium, liquid nitrogen mixed with liquid argon and liquid nitrogen mixed with liquid helium, wherein said coarse titanium or titanium alloy material is a member selected from the group consisting of Ti-6Al-4V, commercially pure titanium and Ti-5Al-2.5Sn, and wherein said coarse titanium or titanium alloy material is a member selected from the group consisting of commercially pure titanium and binary titanium compounds selected from the group consisting of β -Ti-Mo and α -Ti-Al.